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THE EFFECT OF DEPTH SEPARATION
ON LATERAL INTERFERENCE

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Lateral interference is a generic term referring to the inhibitory interference among continuously visible adjacent contours that occupy the same plane in depth, e.g., a string of closely spaced alphanumeric characters. Both theoretical considerations and some data suggest that interference or interaction, for several kinds of visual phenomena, may not occur if the interacting elements occupy different depth planes. By generating stimuli as stereoscopic contours formed

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from dynamic random-element stereograms, the depth position can be easily manipulated without introducing potentially confounding changes in proximal stimulation. This approach in prior research has revealed that the interference between threshold level of transient stimuli, i.e., visual metacontrast masking, is strongly influenced by depth position. The present experiments examined the generality of this observation and determined : (a) if a similar effect is present when one or more of the interacting elements is a supra-threshold, continuously visible stimulus, and (b) if the lateral separation between elements is a significant factor. In four experiments, the interaction between an annulus and a Landolt-C enclosed within it was investigated as a function of their relative depth positions, and of the lateral distance between the inner edge of the annulus and the outer edge of the C. Either one or both of these stimuli were continuously visible. The effect of the annulus on the ring was assessed by forced-choice recognition thresholds of the ring and by judgements of its apparent clarity. The main results were: (a) depth separation has a strong effect on the strength of the interaction; (b) the effect is asymmetrical in that the stimulus which is in front of its partner and closer to the observer has greater perceptual potency; (c) as spacing between the elements increases, interaction declines independent of depth position. The implications of these data for general theories of stimulus interaction in three dimensional space are discussed.

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THE EFFECT OF DEPTH SEPARATION ON LATERAL INTERFERENCE

Lateral Interference is a general term intended to encompass many situations where suprathreshold continuously visible stimuli, all in the same depth plane (Z-axis), are in close spatial proximity (X and Y axes). The key observation from which the notion of interference derives is that a stimulus surrounded by others is less perceptible than when seen in isolation. A ubiquitous example of such interference, described by Woodworth (1938), is provided by horizontal arrays of alphabet letters--letters at the end of the string are more perceptible than embedded ones flanked by partner letters. A second example, from the opthalamic and optometric literature, is the phenomenon known as crowding--in the well-known clinical test of visual acuity known as the Snellen Chart randomly ordered rows of letters are reduced in size in discrete steps. As the acuity threshold of an observer is approached, letters within the row may not be resolvable, yet each individual letter can be seen if presented alone.

Two well-known phenomena closely related to lateral interference are simultaneous contrast and visual masking. In simultaneous contrast, the brightness of a surface can be markedly reduced if it is adjacent to or surrounded by a surface of a higher intrinsic brightness. In visual masking, the perceptibility of transient stimuli is reduced if they occur together closely coupled in space and in time.

1

Theoretical treatments of all these phenomena have regarded them as manifestations of a common underlying lateral inhibitory process derived from the physiological concept of lateral inhibition (e.g., Cornsweet, 1970). This approach considers interaction only in X and Y axes, and does not address the question of the role of the depth position of the stimuli. The failure to consider depth position reflects the widespread assumption that information about the characteristics of stimuli are analyzed first by the visual system. This information is then used (it provides cues) to determine the depth location of stimuli.

But an alternative minority theoretical position, explicit within the Gestalt tradition (e.g., Koffka, 1935), posits an analog representation of visual space within the visual system that assumes depth information is processed either simultaneously or prior to the processing of stimulus information. On that view, interaction and interference between stimuli would not occur if they were sufficiently separated in depth. Some tests of that hypothesis have been made by manipulating cues so that physical stimuli appear to lie at different perceived distances. In the main, the results are supportive--much of the work is reviewed by Gogel (1978), Gilchrist (in press), Fox and Lehmkuhle (1978), and Lehmkuhle and Fox (in press). But a full explication of the hypothesis that stimulus interaction and interference depends upon depth position is impeded by the intrinsic difficulty in manipulating the apparent depth of physical stimuli without introducing potentially confounding differences in retinal stimulation.

An approach that avoids the problem of confounding stimulation while at the same time permitting facile manipulation of large changes in apparent depth is the use of stereoscopic contours generated from random element stereograms (e.g., Julesz, 1971; 1978). The great advantage of such stereograms is that when viewed monocularly, they appear simply to be a random collection of dots without identifiable contours or shapes. But through the operation of stereopsis, when the dot patterns in each eye are combined, the stereoscopic forms are seen in stereoscopic space. In a functional sense, the contours bypass or skip the more peripheral stages of the visual system and arise at the central stages devoted to stereopsis. Even though the stereoscopic contours do not exist as physical luminance gradients impinging on the retina, they can induce illusions, after affects, and other perceptual phenomena similar to those induced by physical contours.

In most of the prior research using these stereograms only static versions (e.g., photographs) were available hence parameters of the stereoscopic configuration were fixed. But quite recent tech-nological developments have made it possible to generate dynamic random element stereograms which permit the parameters of the stereoscopic display to be changed instantaneously--stereoscopic contours can be moved about in stereoscopic space and their config-uration dramatically altered without introducing monocular cues. A system for generating dynamic random element stereograms has been developed at Vanderbilt and used in a variety of research applica-tions (e.g., Fox, Lehmkuhle, & Bush, 1977; Fox, Lehmkuhle, & Leguire,

1978; Staller, Lappin, & Fox, 1980). A description of the electronic portion of the generation system is given in Shetty, Brodersen, and Fox (1979).

With respect to the question of depth separation, the system was used by Fox and Lehmkuhle (1978) and Lehmkuhle and Fox (in press) to investigate the effect of depth separation on visual meta-contrast masking. The test stimulus was a stereoscopic contour configured as a Landolt C whose gap position could be varied to obtain forced-choice recognition thresholds. The masking stimulus was a briefly presented annulus surrounding the ring which could be varied in depth position and onset time relative to the test. The main results were as follows: When test and mask occupied the same depth position, considerable masking was obtained. When the depth position of the test was in front of the mask and closer to the observer, masking declined as a function of increases in depth position between test and mask. When the depth positions were reversed and a mask appeared in a depth plane in front of the test and closer to the observer, masking was enhanced relative to the case where both occupied the same depth plane. The main conclusion derived from the results was that masking was clearly influenced by the depth between test and mask. The asymmetrical nature of the depth dependent relationship, which was termed the front effect, was unexpected. A tentative hypothesis advanced to account for it is based on the notion that whenever objects occupy similar and, possibly, competing visual directions (similar X/Y positions), the stimulus closer to the observer is processed with greater facility or given greater weight by the visual system. In some respects, the concept is related to

the well-known dominance of figure over ground.

The present experiments were inspired directly by the Lehmkuhle and Fox investigation and designed to determine: (a) if the pattern of the results obtained with visual masking was restricted to the interaction of transient stimuli or whether it could be generalized to the case where one or both of the interacting elements are not transient, i.e., where the stimuli conform to the conditions of lateral interference; and (b) to determine if the interaction was influenced by the lateral distance between stimuli. On the hypothesis developed to account for the front-effect, interaction should decline as the lateral distance or, alternatively, the difference in visual direction between stimuli increases.

General Method

Subjects

Four persons, three graduate students and one postdoctoral fellow, were paid for their voluntary participation in the experiments. All four observers had considerable experience in detecting stereoscopic stimuli, yet for these experiments were naive about the hypotheses under test.

Apparatus

Before describing the system for the dynamic generation of random element stereograms, it will be helpful to review the general principles underlying the construction of static random element stereograms of the kind systematically developed by Julesz (e.g., Julesz, 1971). In Figure 1, a typical static random element stereogram is illustrated. Each dot matrix, designed to stimulate a single eye, consists of 10,000 cells, half of which are randomly

Figure 1. The two monocular patterns of a typical static
random element stereogram. When each pattern stim-
ulates a separate eye, a stereoscopic form can be
perceived (after Julesz, 1971).

filled with dots. Although both dot matrices look identical, a subset of dots within the central area of one matrix has been displaced horizontally with respect to corresponding dots in the other matrix. It is this displacement that produces the retinal disparity essential for the induction of stereopsis.

The displacement process is illustrated schematically in Figure 2. The center inner square in one matrix has been shifted laterally by one column, thereby rendering all the dots in the submatrix disparate with respect to corresponding dots in the other matrix. The gap produced by the displacement is filled with the dots (the cells labelled X and Y in Figure 2) that had been covered by the shifted matrix, ie., the column on the right is shifted to the left. All other dots in each of the matrices are identical or, in equivalent terms, are correlated 100% between the eyes. The laterally shifted or displaced sub-matrix, however, cannot be observed under non-stereoscopic viewing conditions because it is camouflaged by the large number of sur-rounding dots. But, when each matrix stimulates a separate eye, the binocular visual system, in effect, compares each matrix and detects the disparity or displacement. This results in the per-ception of the stereoscopic form. In the case of the displaced square shown in Figure 2, it would be seen as a square stand-ing out in depth, with clear-cut, sharp edges, and a solid textured surface.

. There is, however, one potential limitation to this method of introducing disparity, as has been pointed out by Bridgman (1964) and Gulick and Lawson (1976). The practice of filling the gap on
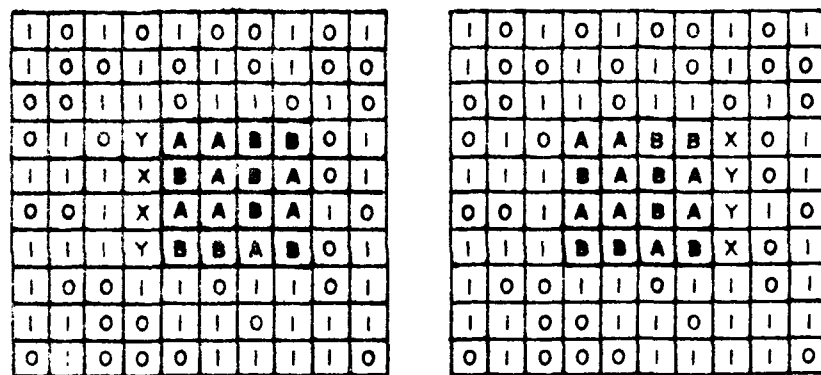
Figure 2. The displacement process for the generation of static random element stereograms (after Julesz, 1971).

one side of the submatrix with those elements from the other side

of the submatrix that are covered by the shift produces columns of

elements unpaired with those in the other matrix; as a result,

these columns are seen as part of the background rather than as

part of the figure. This means that, as disparity is increased,

the size of the figure will be reduced. This reduction is due to

the physical characteristics of the stereogram and is unrelated to

any apparent reduction brought about by size constancy. A

second limitation inherent in all static stereograms is that all

parameters of the stereoscopic form are fixed and cannot be

changed over time. If an attempt is made to introduce changes by

successive presentation, monocular cues produced by apparent mo-

tion are introduced. But, both of these limitations are avoided

in the system for generating dynamic random element stereograms

described below.

Since this system has been discussed elsewhere (e.g., Lehmkuhle

& Fox, in press; Fox & Lehmkuhle, 1978; Shetty, Brodersen, & Fox,

1979) in some detail, only a brief overview is given here. The

system consists of two functional units, the display device and

the electronic generation unit. For this application, however, an

additional component, the optical programming device, has been

added. The interrelationship of these units is shown schematically

in Figure 3.

The display device is a color television receiver modified

so that the red and green guns can be electronically controlled at

the level of the video amplifiers with the blue gun being turned

off. Modulation of the red and green guns produces random dot

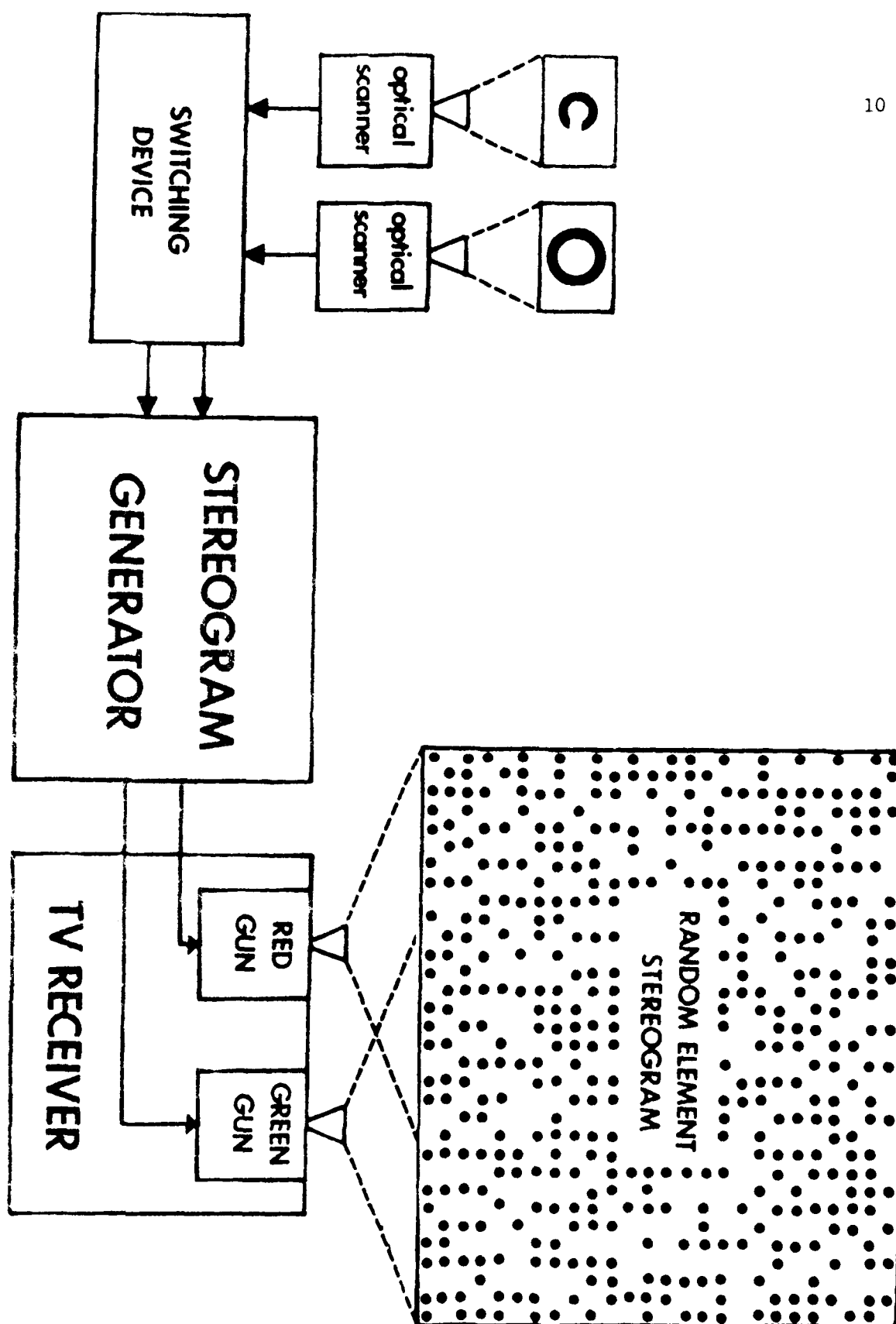matrices composed of red and green dots. When appropriately matched

Figure 3. Display, programming, and logic units of the stereogram generation system.

red and green filters are placed before the eyes of an observer,
the matrices stimulate separate eyes and thereby fulfill the
requirements of stereoscopic viewing. This is, of course, the
well-known anaglyph method of stereoscopic presentation.

The electronic unit that modulates the red and green guns
is a hard-wired device made from high-speed integrated circuits.
It drives the guns in the raster-scan mode at standard video
frequencies. Dot patterns are produced by turning the guns on
and off as they sweep the raster. In previous descriptions of
a system, an explanation of the system has been given in terms of
the behavior of the guns. But this does not readily convey all
of the events occurring electronically. Rather, it is more useful
to think of the system as composed of a series of sub-systems,
with each constructing some portion of the stereogram; all portions
of the stereogram are then presented simultaneously. One might
think of each portion as if it were being prepared on separate
transparent sheets. When all sheets are combined into a montage,
the final complete stereogram results. The electronic sub-systems
assigned particular functions are as follows: (1) The undelayed
dot generation system generates random matrices of red and green
dots without disparity that would, if displayed, completely fill
the screen. (2) The size-shape system specifies the X/Y coordinates
of the stereoscopic form to be displayed. This is done by blanking
the red and green dots produced by the undelayed dot generation
system. If the output of the size-shape system were to be displayed,
one would see a black shape on the screen corresponding to the size
and shape of the to-be-displayed stereoscopic form surrounded by

red and green dots from the undelayed dot generation system.

(3) The dot delay system produces a slight delay in the output of one or the other of the electron guns. This delay results in a difference in spatial position between red and green dots and it is this spatial displacement which provides the retinal disparity essential for stereopsis. The dots that are delayed, however, are only those which fill in the area specified by the size and shape system. When undelayed dots from the other gun also fill in the area, a disparity exists between the delayed dots and the undelayed dots. If the output of all previous stages were to be displayed at this point, one would perceive the stereoscopic form but a vertical gap at one end of the form would also be visible. (4) The gap-filling system, however, provides dots without disparity, which precisely fill in the gap produced by introducing the delay. When all outputs of the systems are combined, by ANDing logic operations, and simultaneously displayed on the television screen, the stereoscopic form can be seen without the presence of monocular cues. In this method of stereogram generation, the size and shape of the stereoscopic form is independent of its disparity thereby avoiding the problem of the correlation between disparity and size inherent in the method of stereogram construction described earlier. In the dynamic mode, all dots in both of the displayed matrices are replaced at random via a random generator at either the field rate, 60 times per second, or the frame rate, 30 times per second of the video receiver. Dot displacement produces a continual apparent motion of the dots similar to the static seen on an untuned TV channel. The apparent motion, however,

does not impair the visibility of the stereoscopic form and permits
the stereoscopic forms to be continuously changed to configura-
tion in X, Y, and Z positions without introducing monocular cues.
The electronic generation unit provides controls for instanta-
neously changing disparity magnitude and direction, X/Y position
of the stereoscopic form, and changes in vertical and horizontal
extent. But the unit, by itself, allows only for the generation
of rectilinear stereoscopic forms.

To overcome this restriction, the optical programming
device makes it possible to present, as a stereoscopic form,
virtually any stimulus configuration. The principle of the pro-
gramming system is similar to that of a flying spot scanner. The
scan of a modified black and white video camera is synchronized
with the sweep of the video receiver. The analogue voltage
emitted by the camera, which varies as it sweeps over contours
varying in luminence, is digitized and used to specify the area
that is to receive the delayed dots -- in effect it controls the
size/shape system. Any black and white two-dimensional configu-
ration scanned by the camera can be converted into a correspond-
ing stereoscopic configuration. The number of configurations
that could be presented simultaneously is governed by the number
of cameras used. The parameters of the stereoscopic configuration
encoded by one camera can be manipulated independently of the
parameters of the stereoscopic configuration encoded by another
camera. By switching between the outputs of cameras, different
configurations can be presented in quick succession. A timing
device provides for precise control of the duration of exposure

of each stereoscopic configuration. Timing duration always begins at the start of a raster scan, thereby removing ambiguity between the nominal onset time and the actual position of the guns during the scan. Durations of exposure are, then, always multiples of either the field or frame rate of the receiver.

The configuration of the system used in the present experiments is illustrated in Figure 4. Two kinds of stimuli were used--an annulus or ring whose size varied and a Landolt C, which was also called the test figure, whose gap position could be randomly varied in one of four clock positions: 12:00, 3:00, 6:00, and 9:00. The annulus surrounded the ring and the depth position and exposure duration of each configuration were independently manipulatable. One camera was dedicated to scanning images of the annulus and the other to images of the Landolt C. The images scanned by the cameras were achromatic, two-dimensional photographs projected as 35mm. slides. A large number of slides were made representing appropriate variations in the stimuli, e.g., variation in the gap of the Landolt C; by ordering the position of the slides in slide trays the sequence of stimulation appropriate for a particular condition could be easily introduced. Note, however, that the projectors and the cameras, in concert, provide only information about where the shape is to be placed along the X and Y axes of the display. The actual exposure duration, depth position and other parameters, of the stereoscopic counterpart of the annulus and Landolt C are controlled by the stereogram generation unit. That unit in turn, sends appropriate signals to the display. Although almost any color televi-
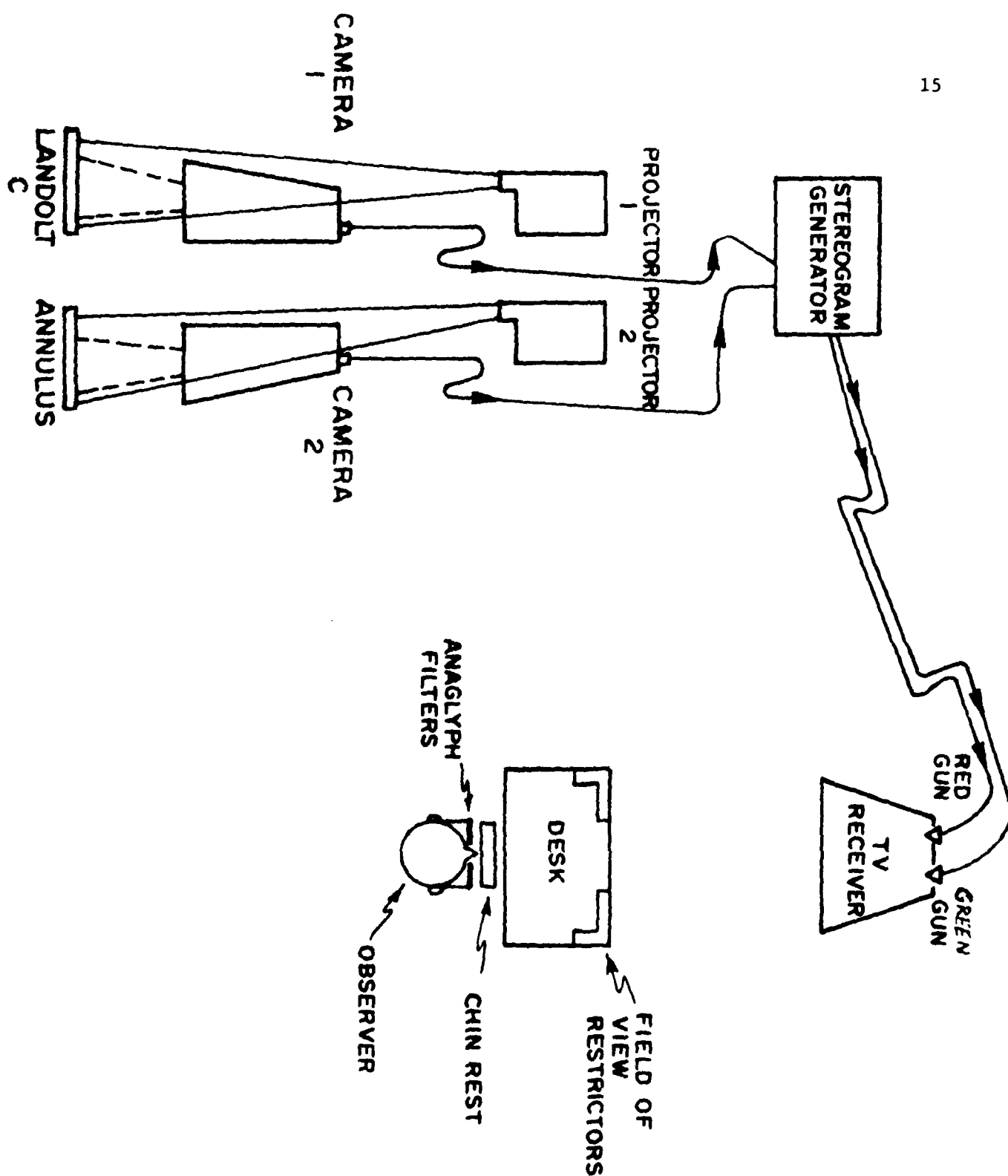
Figure 4. The stereogram generation system as arranged in the experimental room.

sion receiver can be used as a display, for this application the table model shown was the one considered most suitable. The observer viewed the display under constant conditions--fixed viewing distance, restricted field of view and stable head position.

Experiment 1

The purpose of experiment 1 was to investigate the influence of depth separation on the lateral interaction between a briefly presented test stimulus, the Landolt C, and a continuously visible annulus. Interference was measured by obtaining forced-choice recognition thresholds for the gap position of the Landolt C. This test figure subtended an angle of 1.74 deg at the eye, with the gap subtending an angle of 0.88 deg. With respect to the annulus, the inner edge subtended an angle of 3.53 deg, and the outer edge an angle of 7.05 deg. The difference between the angles subtended by the Landolt C and the inner edge of the annulus was 1.79 deg, so that for all conditions the annulus surrounded, but did not overlap the test figure.

The major manipulation was to vary the depth position of the annulus relative to that of the test--that is, the annulus could appear in front of or in back of the test, or both could occupy the same depth plane (see Figures 5 and 6). Specifically, the annulus was placed at each of five depth positions relative to the test: At depth conditions 2 and 3 corresponding to disparities of 6'40" and 13'20", respectively, the annulus was located behind the test. At depth condition 4 corresponding to a disparity of 20'0", both test and annulus were positioned in the same depth
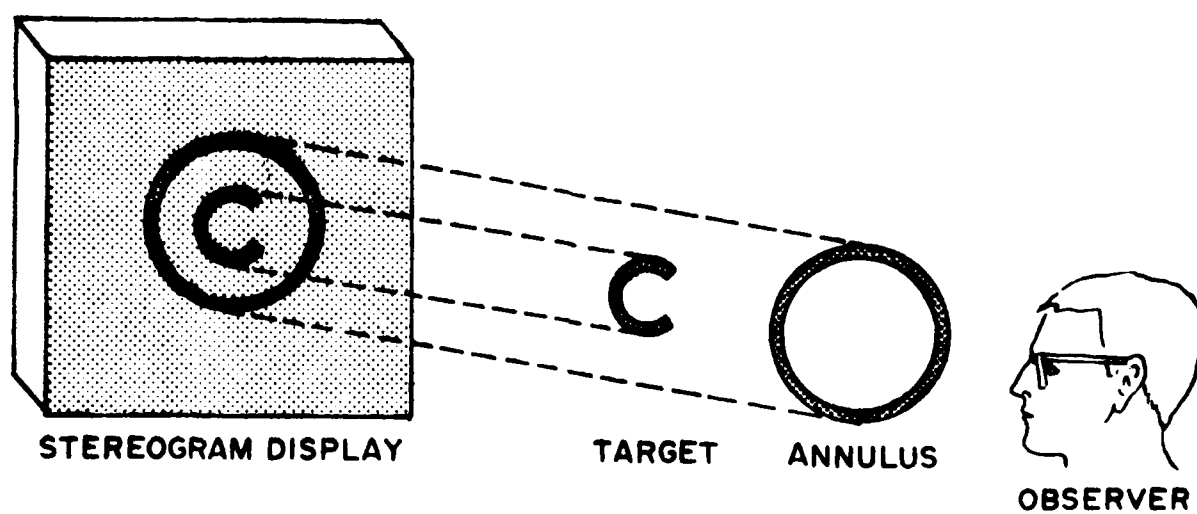
Figure 5. Stimulus arrangement showing relative depth of target
(in back) and annulus.

STEREOGRAM DISPLAY   **ANNULUS**   **TARGET**
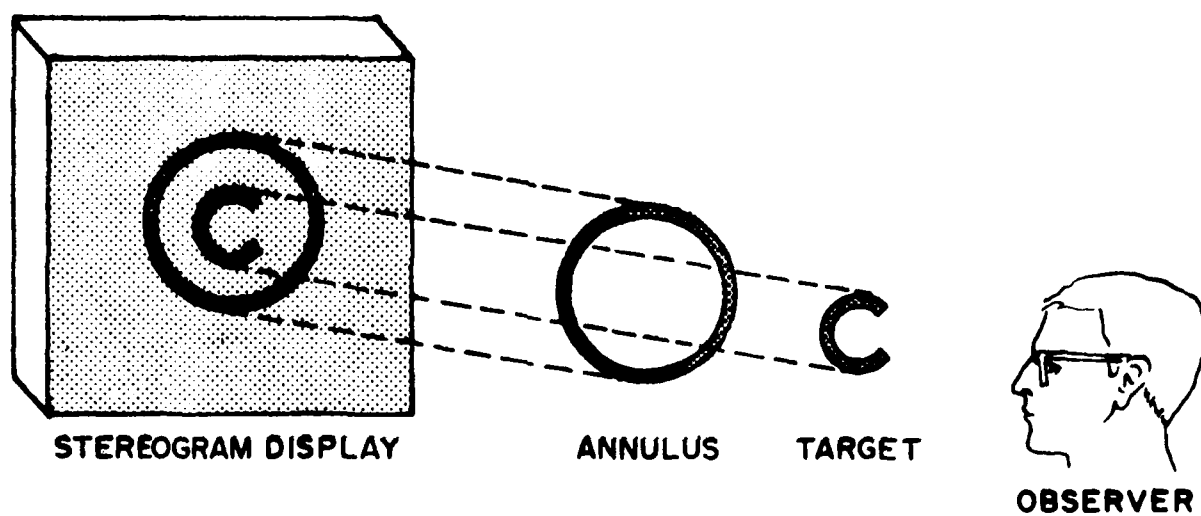
OBSERVER

Figure 6.   Stimulus arrangement showing relative depth of target
(in front) and annulus.

plane. The annulus was positioned in front of the test for depth

conditions 5 and 6, which corresponded to disparities of 26'40"

and 33'20", respectively. The test was always located at disparity

20'0" (depth condition 4).

Procedure

The displays were generated on a Hatachi color TV receiver

(Model CT-925) situated 1.65 m from the observers. When viewing

the display the observers were required to look through a wooden

frame that restricted their field of view to an angle of 49.7 deg.

Training. The general experimental approach involved, as in

other applications of the psychophysical paridigm, the gathering

of considerable data from a small number of trained observers whose

levels of performance had reached asymptotic or steady-state values

prior to final data collection. In this way the effect of inde-

pendent variables can be sharply delineated, and the assumption

of stationarity requisite for data analysis fulfilled. To

achieve this goal, all four observers received considerable

practice in detecting the gap position of the Landolt C test

figure under forced-choice recognition threshold conditions,

with feedback given after every trial. Exposure duration of the

test was varied as performance improved to maintain performance

within the range of 60-80% correct responses. Since the chance

level of performance is 25%, this threshold range provided consi-

derable latitude for detecting reductions in threshold induced by

the annulus. All observers reached steady-state threshold of 60-

80% for exposure durations ranging from 64 msec to 160 msec, with

each duration adjusted for each observer.

Formal Data Collection. Once the observer's thresholds reached asymptotic values, formal data collection began. In daily sessions of 112 trials, the annulus was introduced and its depth position was varied over the five depth conditions 2 through 6. The depth positions were presented in random order for 80 trials. Sixteen trials at the beginning of the session, and 16 at the end, measured threshold without the annulus (pre- and post- session controls) to provide a check on the stability of the baseline threshold.

The gap position of the Landolt C test figure was randomized, with the restrictions of equal occurance of all four positions, and the elimination of runs of more than three consecutive presentations of the same gap position. Changes in the apparent size of the annulus produced by size constancy were compensated so apparent size remained constant over all depth positions. This compensation did not alter the lateral distance between the inner contour of the annulus and the outer contour of the test figure.

Results

Figure 7 shows the mean percent correct recognition for the two control and five depth conditions, and it can be seen that the presence of the annulus in the equal depth condition (condition 4) does impair recognition performance for the test figure, relative to when the test was presented alone (e.g., the two control conditions). Closer inspection of Figure 7 will also reveal an interesting asymmetry of interference following depth manipulations of the annulus: Having the annulus behind the test (conditions 2 and 3) led to improved performance when compared to the situation
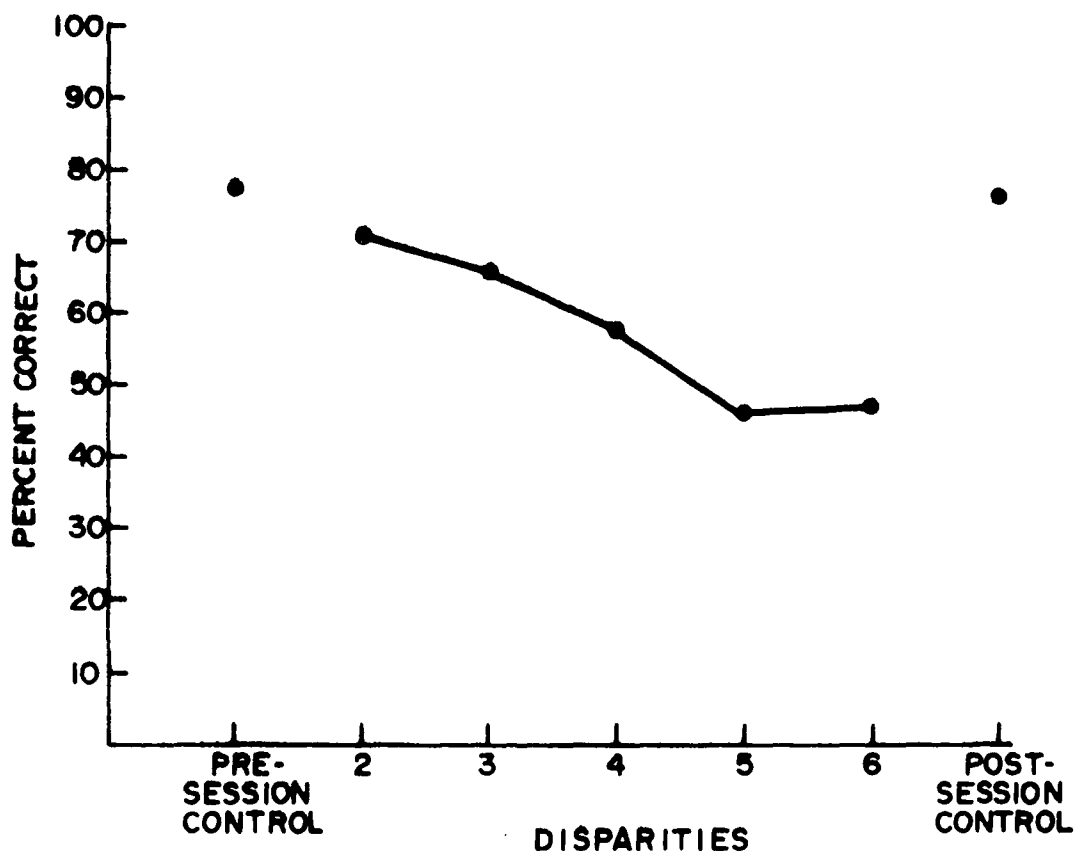
Figure 7. Forced-choice recognition thresholds for pre- and post-session control conditions, in which the test figure was presented without the annulus, and for five depth conditions (disparity conditions 2 through 6) in which test and annulus were presented together (the test was near threshold, and the annulus was suprathreshold). For depth conditions 2 and 3, the annulus was positioned behind the test figure, and for depth conditions 5 and 6, the annulus was located in front of the test. For depth condition 4, both test figure and annulus occupied the same depth plane.

TABLE 1

TWO-WAY ANALYSIS OF VARIANCE SUMMARY TABLE FOR EXPERIMENT 1

Source	Sum of Squares	df	Mean Square	F-Ratio
Between Error	5842.45	3	1947.48	
Depth Conditions	8591.35	6	1431.89	7.859*
Within Error 1	3279.66	18	182.204	
Sessions	3.02002	1	3.02002	
Within Error 2	1512.51	3	504.169	
Depth Conditions by Sessions	594.351	6	99.0585	
Within Error 3	2040.56	18	113.364	
Total	21863.9	55	397.525	

*$p < .001$

TABLE 2

NEWMAN-KEULS TEST FOR TREATMENT MEANS OBTAINED UNDER TWO
CONTROL AND FIVE DEPTH CONDITIONS FROM EXPERIMENT 1

| Depth Condition | | Depth Condition | | | | | | |
		$\frac{6}{45.5}$	$\frac{5}{45.625}$	$\frac{4}{57.00}$	$\frac{3}{65.875}$	$\frac{2}{70.625}$	$\frac{\text{Post-Control}}{76.00}$	$\frac{\text{Pre-Control}}{77.00}$
6	45.5	---						
5	45.625		---					
4	57.00			---				
3	65.875	**	**		---			
2	70.625	**	**	*		---		
Post-Control	76.00	**	**	**			---	
Pre-Control	77.00	**	**	**				---

* $p < .05$
** $p < .01$

where both test and annulus were in the same depth plane (condition 4). Conversely, when the annulus was placed in front of the test (conditions 5 and 6), performance decreased compared to the equal depth condition (condition 4). A two-way Analysis of Variance (ANOVA) for repeated measures, shown in Table 1, revealed a significant effect of depth position upon percent correct recognition, $F(6, 18) = 7.86$, $p < .001$. A Newman-Keuls test for these means was also computed, and the results are given in Table 2. There was no significant effect of sessions upon percent correct recognition. The discussion of these results, and of the results from the other experiments in this series will be deferred until the Discussion section.

Experiment 2

The purpose of experiment 2 was to examine the effect of depth separation on the lateral interference between two continuously visible, suprathreshold stimuli--the Landolt C and the annulus. Interference in this situation was measured by obtaining ratings of apparent clarity of the Landolt C from the observers. Prior observations have suggested that the apparent clarity of the test stimulus will vary as a function of the depth position of the annulus relative to that of the test figure. Clarity ratings, therefore, are an appropriate method for measuring interference between suprathreshold stimuli. Note that in this situation, changes in apparent clarity could not result from alterations in proximal stimulation, nor from motion parallax. With respect to the latter, it is well-known that stereoscopic percepts do not yield parallactic information. Rather, any movements of the head in one direction will typically cause the stereoscopic forms to

appear to move with the observer in the same direction. Accordingly, in the present experiment the test figure would still appear centered within the annulus in spite of any lateral head movements produced by the observers.

Procedure

The clarity ratings were obtained in the following way: The observers were required to rate the perceived clarity of the test figure on a seven point scale, with 1 indicating "not clear," and 7 indicating "very clear." In this experiment the test figure was continuously visible with the orientation fixed at 9:00. All depth positions of the annulus relative to the test figure were the same as in experiment 1. The one control and five disparity conditions, three trials each, were randomly presented to the observers. Apparent size of the annulus remained constant throughout all depth manipulations.

Results

Figure 8 shows the observers' ratings of perceived clarity for the one control and five depth conditions. It can be seen that, similar to the data from the first experiment, rated clarity was less when the annulus was presented with the test in the equal depth condition (condition 4), relative to when the test was presented alone. Moreover, an asymmetry of interference following depth manipulations of the annulus can again be seen: When the annulus was placed behind the test (conditions 2 and 3), rated clarity was greater than when both annulus and test occupied the same depth plane (condition 4). And, when the annulus was presented in front of the test figure (conditions 5 and 6) rated
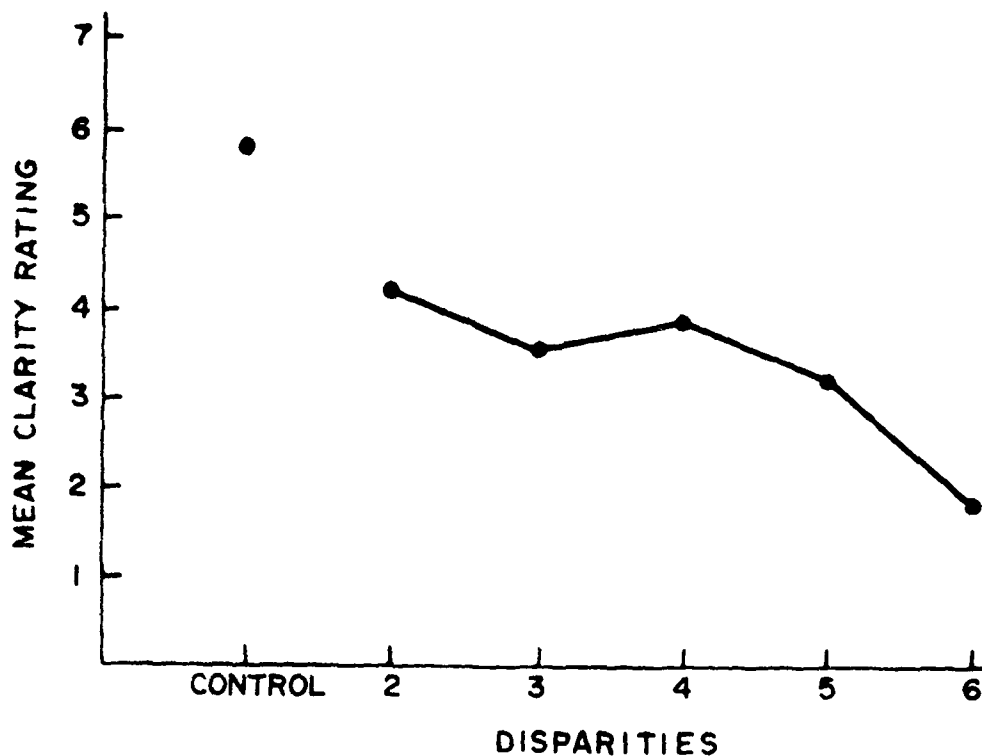
Figure 8. Clarity rating scores for the control condition, in which the test figure was presented in isolation, and for five depth conditions (disparity conditions 2 through 6) in which test and annulus were presented together (both test and annulus were suprathreshold). For depth condition 4, both test and annulus occupied the same depth plane. For depth conditions 2 and 3, the annulus was seen behind the test, while for depth conditions 5 and 6, the annulus was positioned in front of the test figure.

TABLE 3

ONE-WAY ANALYSIS OF VARIANCE SUMMARY TABLE FOR EXPERIMENT 2

Source	Sum of Squares	df	Mean Ratio	F-Ratio
Between Error	4.56500	3	1.52167	
Depth Conditions	34.3533	5	6.87066	7.436*
Within Error 1	13.8599	15	.923992	
Total	52.7782	23	2.29470	

*p = .001

TABLE 4

NEWMAN-KEULS TEST FOR TREATMENT MEANS OBTAINED UNDER ONE
CONTROL AND FIVE DEPTH CONDITIONS FROM EXPERIMENT 2

Depth Condition		Depth Condition					
		$\dfrac{6}{1.75}$	$\dfrac{5}{3.15}$	$\dfrac{3}{3.50}$	$\dfrac{4}{3.825}$	$\dfrac{2}{4.175}$	$\dfrac{C}{5.75}$
6	1.75	---					
5	3.15		---				
3	3.50	*		---			
4	3.825	*			---		
2	4.175	*				---	
C	5.75	**	*	*	*	*	---

* $p < .05$
** $p < .01$

clarity was less than that demonstrated for the equal depth condition (condition 4). A one-way ANOVA for repeated measures (see Table 3) revealed a significant effect for depth conditions upon clarity ratings, $F(5, 15) = 7.44$, $p < .001$. The results from a Newman-Keuls test computed for these means is shown in Table 4.

Experiment 3

Given that experiments 1 and 2 demonstrated lateral interference between the Landolt C and annulus to be significantly influenced by their relative depth positions, experiment 3 tested the conjecture that the degree of lateral separation between the two stimuli would also affect their interaction. Similar to experiment 2, both the test figure and annulus were continuously visible; therefore, ratings of apparent clarity were again obtained from the observers.

All depth positions of the annulus relative to that of the test figure were the same as in experiments 1 and 2. In addition, three values of lateral separation between the inner edge of the annulus and the Landolt C were employed: (a) a lateral separation of 2.78 deg; (b) a lateral separation of 3.82 deg; and (c) a lateral separation of 4.86 deg. These three values of separation will be referred to as Annulus B, Annulus C, and Annulus D, respectively. The original value of lateral separation of 1.79 deg will be hereafter referred to as Annulus A. The complete dimensions of these stimuli are shown in Figure 9.
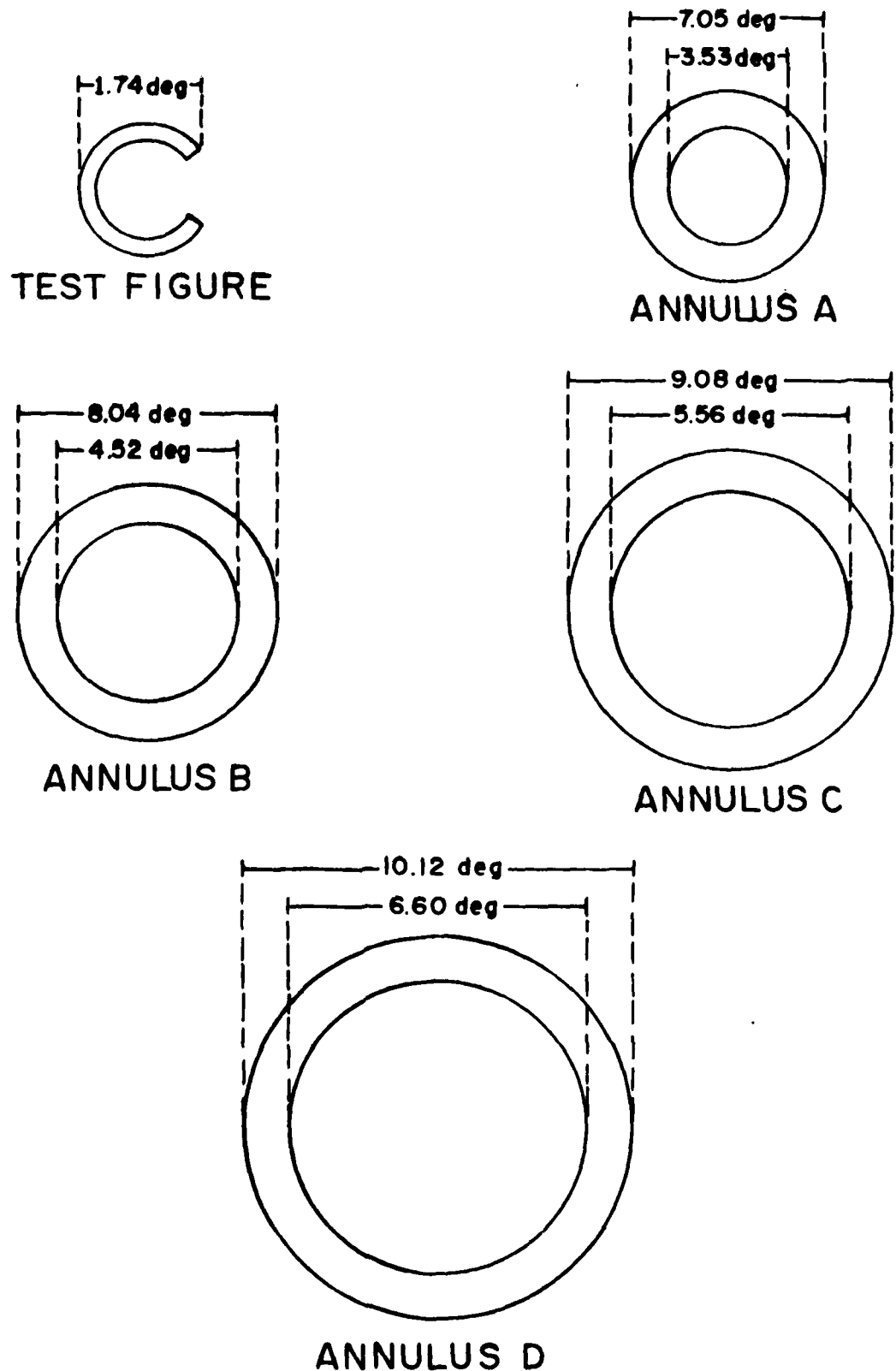
Figure 9. Dimensions of test figure and four annuli employed in experiment 3. Both the test figure and annulus A were used in experiments 1 and 2. In experiment 4, the test figure and annuli A and D will be employed.

Procedure

The one control and five disparity conditions were presented a total of 4 trials for each of the three annuli. During all depth manipulations the apparent size of the annuli remained constant.

Results

Because experiment 2 employed the same observers under essentially the same conditions as the present experiment, clarity ratings for the smallest value of lateral separation employed in experiment 2--Annulus A with a separation of 1.79 deg--were included in the present data analysis. The data are plotted in Figure 10. Considering all four annuli, rated clarity for the test figure again was less when the annuli were presented with the Landolt C in the equal depth condition (condition 4), relative to the control condition. Moreover, following depth manipulations of the annuli ratings of perceived clarity were again asymmetrical: Clarity was perceived greater when the annuli were positioned behind the test figure, and less when the annuli were located in front of the Landolt C, relative to the equal depth condition. A two-way ANOVA for repeated measures, with the control group excluded from the analysis, indicated these differences for disparity conditions to be statistically significant, $F(4, 12) = 6.54$, $p = 0.005$ (see Table 5). Next, a Newman-Keuls test for these means was computed, and the results are shown in Table 6. (Note that the control group was included in the Newman-Keuls analysis, and that the scores for this condition were obtained by averaging, for each observer, the control group data from experiment 2 with the control group data from the present experiment.)
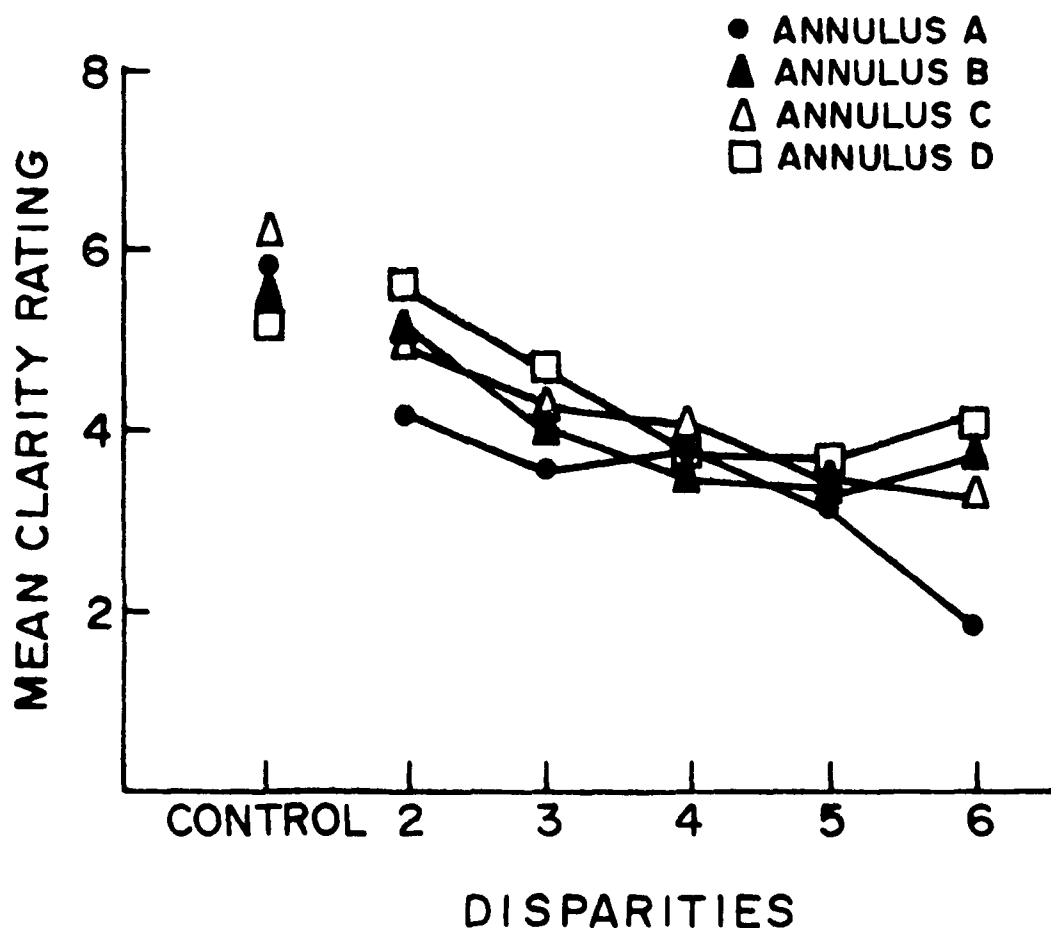
Figure 10. Clarity rating scores for the control condition, in
which the test figure was presented without the annulus,
and for five depth conditions (disparity conditions 2
through 6) in which test and annulus were presented
together (both test and annulus were above threshold).
For depth conditions 2 and 3, the annulus was established
behind the test figure, and for depth conditions 5 and 6,
the annulus was located in front of the test figure.
Both test and annulus occupied the same depth plane for
depth condition 4. Four different annuli were employed,
ranging in size from annulus A, the smallest, to annulus
D, the largest.

TABLE 5

TWO-WAY ANALYSIS OF VARIANCE SUMMARY TABLE FOR EXPERIMENT 3

Source	Sum of Squares	df	Mean Square	F-Ratio
Between Error	30.5473	3	10.1824	
Annuli	12.3146	3	4.10487	4.085*
Within Error 1	9.04294	9	1.00477	
Depth Conditions	31.3277	4	7.83192	6.536**
Within Error 2	14.3790	12	1.19825	
Annuli by Depth Conditions	9.14552	12	0.762127	2.494*
Within Error 3	11.0032	36	0.305645	
Total	117.760	79	1.49064	

*$p < .05$
**$p < .01$

TABLE 6

NEWMAN–KEULS TEST FOR TREATMENT MEANS OBTAINED UNDER ONE
CONTROL AND FIVE DEPTH CONDITIONS FROM EXPERIMENT 3

Depth Condition		Depth Condition					
		$\dfrac{6}{3.25}$	$\dfrac{5}{3.4437}$	$\dfrac{4}{3.7844}$	$\dfrac{3}{4.1875}$	$\dfrac{2}{5.0125}$	$\dfrac{C}{5.7225}$
6	3.25	---			*	**	**
5	3.4437		---		*	**	**
4	3.7844			---		**	**
3	4.1875				---	*	**
2	5.0125					---	*
C	5.7225						---

*$p < .05$
**$p < .01$

TABLE 7

NEWMAN-KEULS TEST FOR TREATMENT MEANS OBTAINED UNDER ONE
CONTROL CONDITION AND FOUR ANNULI FROM EXPERIMENT 3

Annuli			Annuli			
		A 3.280	B 4.025	C 4.125	D 4.3125	Cont. 5.7225
A	3.280	---	*	*	*	**
B	4.025		---			**
C	4.125			---		**
D	4.3125				---	**
Cont.	5.7225					---

*$p < .05$
**$p < .01$

Clarity ratings were seen to increase monotonically with the size of lateral separation between the inner edge of the annulus and the test figure. Accordingly, the smallest value of separation, Annulus A, received the lowest ratings, while the largest value, Annulus D, received the highest ratings. The two-way ANOVA found these differences to also be statistically significant, $F(3,9) =$ 4.09, $p < 0.05$ (see Table 5). The Newman-Keuls analysis for these means is given in Table 7.

Finally, there was a significant interaction between disparity conditions and lateral separation, $F(12, 36) = 2.49$, $p < 0.02$ (see Table 5 and Figure 10).

Experiment 4

Employing the more rigorous forced-choice threshold task, the purpose of experiment 4 was to again test the hypothesis that the degree of lateral separation between the test figure and annulus would influence their interaction. The measurement of interaction or interference was essentially the same as that used in experiment 1. However, only three depth conditions from experiment 1 were employed in this experiment: (a) depth condition 2, which corresponded to a disparity of 6'40" (annulus located behind the Landolt C); (b) depth condition 4, which corresponded to a disparity of 20'0" (both the test figure and annulus were positioned in the same depth plane); and (c) depth condition 6, which corresponded to a disparity of 33'20" (annulus located in front of the Landolt C). Only one value of lateral separation was employed: Annulus D, the largest value of separation (4.86 deg) used in experiment 3. When the results from the present experiment are combined with those from

experiment 1, forced-choice recognition thresholds for both the smallest and the largest values of lateral separation, Annulus A and Annulus D, are obtained.

Procedure

The subjects participated in one session that was similar to the experimental sessions of experiment 1. The important differences between these two procedures were: (a) only a pre-control condition was used involving 12 trials; (b) the three depth conditions were presented in random order for 72 trials.

Results

Because experiment 1 employed the same observers under similar conditions as in the present experiment, recognition scores for Annulus A from experiment 1 were included in the present analysis. Figure 11 shows the mean percent correct recognition for the one control and three disparity conditions for both Annulus A and Annulus D. It appears that the presence of the annuli in the equal depth condition did produce a decrement in performance relative to the control condition. Similar to the asymmetry of interference seen from experiment 1, positioning the annuli in front of the test figure (depth conditions 5 and 6) led to decreased performance compared to the equal depth condition (condition 4), while positioning the annuli behind the Landolt C led to an increase in
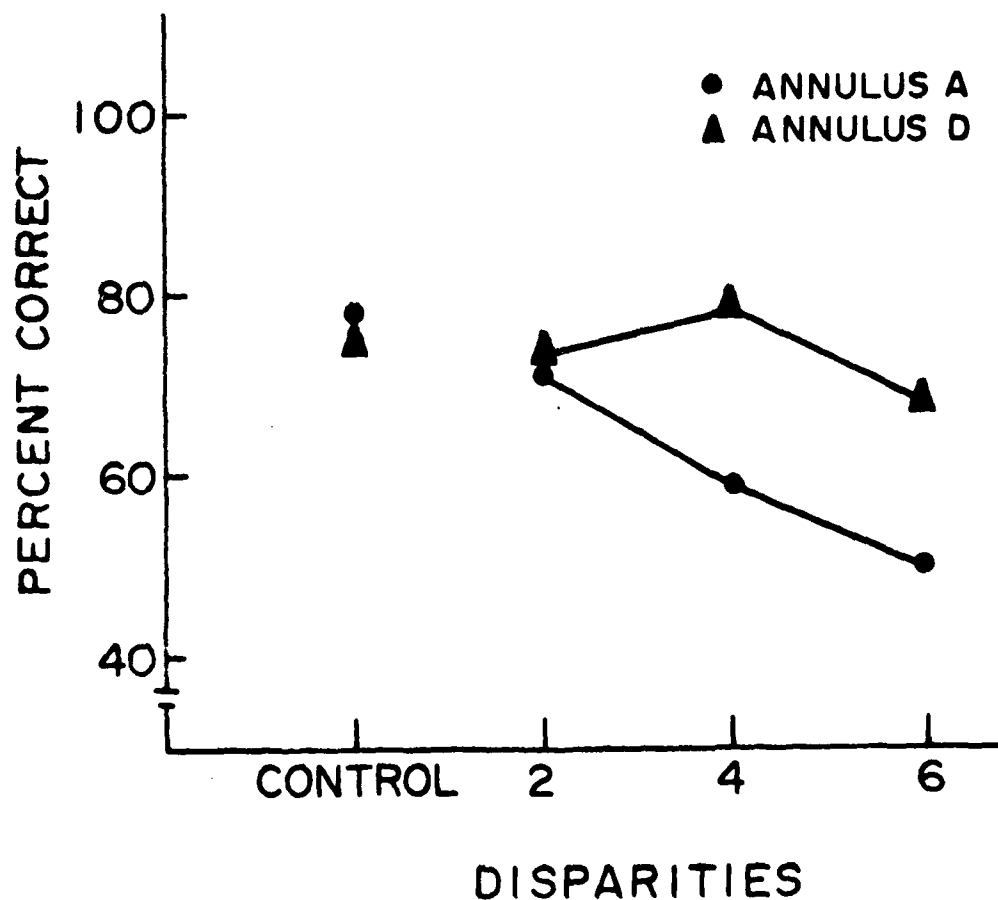
Figure 11. Forced-choice recognition thresholds for the control
condition, in which the test was presented without the
annulus, and for three depth conditions (disparity condi-
tions 2, 4, and 6) in which the test figure and annulus
were presented together (the test was near threshold, and
the annulus was suprathreshold). For depth condition 2,
the annulus was seen behind the test figure, and for
depth condition 6, the annulus was positioned in front of
the test. For depth condition 4, both test and annulus
occupied the same depth plane. Two annuli were employed,
annulus A (the smallest) and annulus D (the largest).

TABLE 8

TWO-WAY ANALYSIS OF VARIANCE SUMMARY TABLE FOR EXPERIMENT 4

Source	Sum of Squares	df	Mean Square	F-Ratio
Between Error	1382.79	3	460.930	
Annuli	1247.04	1	1247.04	2.685
Within Error 1	1393.45	3	464.485	
Depth Condition	1072.0	2	536.0	8.546*
Within Error 2	376.328	6	62.7213	
Annuli by Depth Condition	444.333	2	222.166	1.306
Within Error 3	1020.66	6	170.109	
Total	6936.60	23	301.591	

*$p < .02$

TABLE 9

NEWMAN-KEULS TEST FOR TREATMENT MEANS OBTAINED UNDER ONE
CONTROL AND THREE DEPTH CONDITIONS FROM EXPERIMENT 4

Depth Condition		Depth Condition			
		6	4	2	C
		55.875	66.875	71.875	76.0
6	55.875	---			
4	66.875		---		
2	71.875			---	
C	76.0			*	---

*p < .05

performance (depth conditions 2 and 3). A two-way ANOVA for
repeated measures, computed with the control group excluded, revealed
these differences to be statistically significant, $F(2, 6) = 8.55$,
$p < 0.02$ (see Table 8). In Table 9 the results from a
Newman-Keuls analysis computed for these means are shown. (As was
true for experiment 3, the control group was included in the present
Newman-Keuls analysis. The data for this control group was obtained
by averaging together the scores from the pre-control condition
from experiment 1 with the control group from the current experiment.)

There was a trend toward improved recognition performance
for Annulus D as compared to that obtained for Annulus A; this
difference, however, did not reach significance. Finally, there
was no significant interaction between disparity conditions and
lateral separation.

Discussion

The purpose of this section is to review briefly results of
each of the experiments and to consider the conclusions they
support.

The reduction in recognition accuracy when annulus and test
figure were in the same depth plane, relative to the control condi-
tion where the test was presented without the annulus, demonstrates
that the annulus did exert an inhibitory or interfering effect upon
the test figure. That interference, however, was clearly dependent
upon the relative depth positions of annulus and test figure. When
the annulus was displaced rearward in depth towards the display and
away from the observer, the interference was reduced as revealed by
the increase in recognition performance.

This pattern of results is quite similar to those observed by Fox and Lehmkuhle (1978) and Lehmnkuhle and Fox (in press) in their investigation of metacontrast masking, wherein both annulus and test were transient stimuli. The two main conclusions derived from their study also apply equally well to the present results. First, interference is strongly influenced by depth position. Second, the influence is asymmetrical, following the pattern which Lehmkuhle and Fox called the front effect. Concerning the present investigation, the presence of depth dependency and asymmetry under the conditions of experiment 1, however, suggests very strongly that those phenomena are not restricted to the conditions of transient stimulation associated with visual masking. It is also worth noting that under transient conditions stimuli are typically presented too briefly to permit eye movements; at least that was the case in the Fox and Lehmkuhle and Lehmkuhle and Fox experiments. But in experiment 1, the continual presence of the annulus and its manipulation in depth made it possible for eye movements to have played some role. The great similarity, however, between the present results and those obtained under transient conditions suggest that eye movements were not a contributing factor.

In experiment 2 both stimuli, annulus, and test figure were continuously visible, and these are the conditions which most closely resemble any of the specific instances of lateral interference. Indeed, the same stimulus configurations, annulus, and Landolt C have been used in investigations of the crowding phenomena (e.g., Flom, Heath, & Takahashi, 1965). Moreover, the dependent variable of experiment 2, the rating of clarity, corresponds

very closely to an index of acuity as would be defined by the
ability to resolve clearly an alphabet letter. With respect to the
effect of the annulus and its position in depth on the clarity of
the test, the results from experiment 2 are quite similar to those
observed in experiment 1. Therefore, the results from experi-
ments 1 and 2 taken together provide further support for the
hypothesis that the dependency of interference on depth position,
and the asymmetry of that dependency (i.e., the front effect),
are not unique to threshold level transient stimuli. Rather, the
phenomena of depth dependency and asymmetry apply generally to
those situations subsumed under the concept of lateral interference.

Experiment 3 tested the hypothesis that interference would
decline as lateral separation between annulus and test increased,
and using clarity rating as a dependent variable, this was the
result obtained. Experiment 4 tested the same hypothesis but
used recognition thresholds as the dependent variable. Yet, in
this case, while there was a trend towards decreasing interference
for increases in lateral separation, the difference in recogni-
tion scores did not reach an acceptable significance level--.20
rather than .05 or .01. This difference between experiments 3 and
4 probably reflects a difference in the sensitivities of the two
dependent variables. It is, therefore, very likely that if lateral
separation had been increased further, the difference in recog-
nition scores would have become significant. Taken together, the
results of experiments 3 and 4 suggest that interference and the
depth dependent relationships observed in experiments 1 and 2
come about when stimuli have small lateral separations, or in

equivalent terms, when they have visual directions in close spatial proximity.

The more general conclusion supported by the results of all experiments is that the dependency of interference on depth position, and the asymmetrical nature of that dependency (e.g., the front effect), are phenomena that can be generalized to the many situations encompassed by the term lateral interference. Evidence for depth dependency underscores the incompleteness of theories of interference based upon the concept of lateral inhibition, and gives general support to the view that information about the location of objects in depth is processed either prior to or simultaneously with information about the characteristics of individual stimuli. Although much more research must be done, support for this point of view will have rather fundamental implications for the way in which the processing of perceptual information is conceptualized.

The asymmetrical nature of the depth dependency, that is the front effect, is a new and intriguing observation which is not readily fit into existing theoretical frameworks. Fox and Lehmkuhle (1978) and Lehmkuhle and Fox (in press) speculated that when stimuli are close together in space or in time, the one closest to the observer receives in some sense preferential processing, or is given greater weight by the perceptual system. They suggest that it would have been adaptive for the system to have evolved such a positive bias for the closest stimulus. On this view, the stimulus that is closest to the observer, in almost every situation, is the one that demands the greatest attention and perhaps the most immediate

response. That speculation, however, does not really account for
the relationship known as the front effect—at best it provides
some aura of plausibility.

A slightly different way of thinking about the front effect
that might be helpful is to note its strong family resemblence
to the figure-ground phenomena studied by the Gestalt psychologists.
Whenever a stimulus configuration is perceived as a figure, it is
always seen to be in front of or on top of the ground, and hence
closer in depth to the observer than the corresponding ground. In
addition to this perceptual dominance of figure over ground, the
figure is also endowed with other perceptual advantages. For
instance, as Koffka (1935) points out, the threshold for detecting
a dim light flash is lower when it is imposed upon figure rather
than on ground, even though the physical conditions of stimulation
are identical in both cases. The parallel with the perceptual
advantage enjoyed by the front stimulus observed in these experi-
ments is suggestive, but obviously much more work must be done
before one can seriously consider the proposition that either the
front effect is a special case of figure-ground phenomena, or
alternatively, that figure-ground phenomena are a special case of
the front effect. Nevertheless, what does seem clear is that many
theories designed to account for perceptual interactions in two
dimensions must undergo extensive elaboration and modification to
provide an adequate account for perception in three dimensions.

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